BINARY PULSE POSITION MODULATION (BPPM) BIT ERROR RATE (BER) ANALYSIS IN TURBULENT ATMOSPHERE

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Abstract

The major limitation of free space optical communication system performance is due to the atmosphere eventhough there are high technical advancement of available components. In atmospheric scenario, the high impairment comes from scintillation induced by atmospheric turbulence. The suitable modulation should be use to get the best system performance. From previous research, it is proven that Pulse Position Modulation (PPM) shows better performance compared to On-Off Keying (OOK) modulation for intensity modulation with direct detection. In this paper, binary pulse position modulation (BPPM) is studied when atmospheric turbulence occurs. The performance of this modulation system evaluates in terms of the bit error rate and eye diagram. The simulation system links are done to observe the BER performance. The BER is investigated for various parameters such as gain of photodetector and various scintillation index.

Keywords: *Atmospheric turbulence, Binary Pulse Position Modulation, Bit Error Rate, Simulation System.*

I. INTRODUCTION

FREE space optical (FSO) communication systems is the next generation indoor and outdoor wireless broadband laser application. This technology uses line of sight link, which means the transmitter and receiver has to be able to see each other without any obstacles [1]. FSO systems commercially use wavelengths close to the visible spectrum. FSO has the ability to offer very high data rate, therefore making it a cost effective and high bandwidth access technique [2-3].

FSO currently uses intensity modulation with direct detection (IM/DD) because this system is associated with complexity of phase and frequency modulation [4]. On the other hand, practically, FSO performance can be degraded and scintillation induced by atmospheric turbulence as a major destruction. Atmopheric turbulence happens due to variations in the index of refraction caused by temperature fluctuation. This atmospheric turbulence's impact is it can cause random variations in signal intensity.

Most common atmospheric modulation formats using intensity of photon are On-Off Keying (OOK) and Pulse Position Modulation (PPM). A system using PPM have some advantages over OOK. PPM has high power efficiency compared to OOK since satellite communication links need high peak laser power stage to survive big losses during transmission of signal [4]. OOK system may suffer synchronization loss if a sequence of zero is encountered. This is different with PPM because in PPM, pulse is present in the symbol frame regardless of the transmitted symbol [5]. Q-switched laser; the current technology of laser also cannot be toggled between on and off state at a very high rate. This is limiting the data rate that can be supported by OOK.

The rest of the paper is organized as follows: principle of PPM and atmospheric turbulence are given in section 2, the methodology of the study is provided in section 3, which is followed by results and discussion in section 4. Finally, conclusion remarks are given in section 5.

II. PRINCIPLE OF STUDY

A. Pulse Position Modulation Transmission Scheme

PPM has been recommended for various laser space communications including planetary missions by NASA [6]. PPM is an orthogonal signaling and it uses the same transmitter and receiver hardware used for OOK [7]. In PPM, the position of the pulse determines the data word. For binary PPM (BPPM), two bits are transmitted in a symbol for transmission.

In BPPM, an optical pulse is placed in one of two adjacent time slots to represent the data block. The optical block encoding is achieved by converting each block of two bits into one of optical fields for transmission. At the receiver, decoding of each block is achieved by determining which of the fields is being received during each block time.

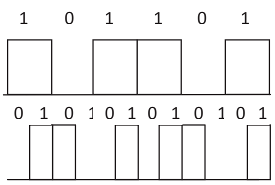


Fig. 1. OOK and BPPM signals

Figure 1 shows the signals of OOK and BPPM. Time slot for one BPPM symbol is equal to time slot for one bit in OOK. A BPPM symbol carries two slots and the position of the pulse in the symbol acts as a data signal. One bit in OOK determines the position of the pulse in BPPM symbol. For example, if ‘1’ bit transmitted in OOK, pulse in BBPM located at the second slot is in a symbol and if ‘0’ bit is transmitted, pulse in BPPM is located at the first slot in a symbol.

In FSO system, the BER of BPPM when only thermal noise and background noise are considered is [4, 8-9]

$$BER = Q\left(\sqrt{SNR}\right) = Q\left(\sqrt{\frac{K_s^{\,2}}{FK_s + K_n}}\right) \qquad (1)$$

where K_s is average signal photons per BPPM slot, K_n is noise considered and F is excess noise factor of photodetector. This BER is not included scintillation of atmospheric turbulence. The BER including scintillation is done in [5, 9-10] using log normal distribution channel and Hermite polynomial simplification as

$$P_b \approx \frac{1}{\pi} \sum_{i=-N, i\neq 0}^{N} w_i Q\left(\frac{e^{2\left(\sqrt{2}\sigma_k x_i + m_k\right)}}{Fe^{\sqrt{2}\sigma_k x_i + m_k} + K_n} \right) \qquad (2)$$

with w_i and x_i are weight factors and zeros factors of Hermite polynomial.

The variance, σ_k^2 for this equation (2) can be determined if the scintillation index of atmospheric turbulence, σ_{sc}^2 is given. This is related since

$$\sigma_k^2 = \ln(\sigma_{sc}^2 + 1) \qquad (3)$$

B. Theory of Atmospheric Turbulence

Atmospheric turbulence is generated by temperature difference between the Earth’s surface and the atmosphere [11]. This scenario happens when during daytime; the Earth is hotter than air, causing the air nearest to the ground to be hotter than that above. This negative temperature gradient caused the light waves parallel to the Earth to bend upwards. But for night-time, the temperature gradient is positive, making the light waves to bend downwards.

Atmospheric turbulence can cause to the incresing BER because for any type of detectors, the BER is functionally related to the signal strength, s which can be defined as the number of signal photons per bit incident on the detector [7]. The signal strength, s becomes a random variable when it fluctuates due to atmospheric turbulence. The BER also will become a random variable.

The common statistical informations of BER are located in the first two moments of the distribution. They are the mean and the variance. Since the BER curve is decreasing with the signal strength, s, but more slowly as s increased, the BER at that point is greater than the other point. So, the average value of BER is biased upward from its value at *s*.

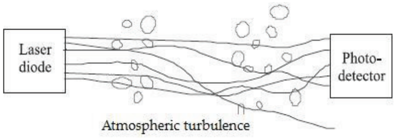


Fig. 2. Cells of turbulence in optical path

Atmospheric turbulence can happen in the whole path length; between transmitter and receiver or only in the certain place along the optical path. These variations and wind speed fluctuations make local unstable air masses, causing them to break up into different sizes of turbulent cells [11]. The atmospheric turbulence represents by scintillation index in this studies. Weak atmospheric turbulence is characterized by scintillation index from 0 to 0.75. Therefore, strong turbulence is presented by scintillation index of 1 [10].

For σ_{sc}^2 << 1, Rytov approximation shows the the relationship of optical intensity and refractive index structure parameter [12]

$$\sigma_{sc}^2 = 1.23 C_n^2 k^{7/6} L^{11/6} \qquad (4)$$

where k is wave number, L is between transmitter and receiver and C_n^2 is refractive index structure parameter.

Since the performance evaluation is done using optical signal attenuation, Rytov relationship shows this equation [13]

$$\alpha^t = 2\sqrt{23.17 C_n^2 k^{7/6} L^{11/6}} \qquad (5)$$

III. METHODOLOGY

In this paper, the performance of BPPM in atmospheric turbulence is done by simulation using Optic Software (OptiSys). The BPPM modulator converts bits of information into electrical signal. Then, it modulates the laser to generate an optical signal. In BPPM, the bits will transmit in frame and the position of the pulse determines the data signal. After that the telescope will expand the optical beam to reduce diffractive effects that spread out the beam.

Table 1. Simulation system parameters

Parameters	Description
1) Photodetector	Avalanche Photodiode (APD)
2) Bit rate	2.4 Gbps
3) APD gain	50 - 200
4) APD ionization ratio	0.028
5) Light source	Laser
6) Scintillation index	Weak turbulence: 0 - 0.75 Strong turbulence: 1
7) Wavelength	1550 nm
8) APD dark current	10^{-14} amp/cm^2

The optical signal then propagates through atmospheric channel. The demodulator converts the optical signal back to the electrical signal. Figure 3 shows the flow chart of the simulation system. The system is monitored by oscilloscope to determine the correct signal. Therefore, table 1 shows the parameter that is used in the simulation system.

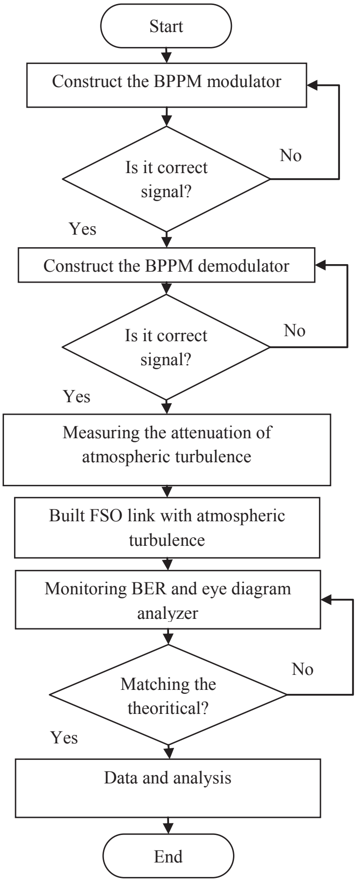


Fig. 3. Simulation system flow chart

IV. RESULTS AND DISCUSSIONS

Figure 4 shows the BPPM simulation system signals collected using oscilloscope. There are four types of signals; the clock signal, the information signal, the modulated signal and detected signal at the receiver.

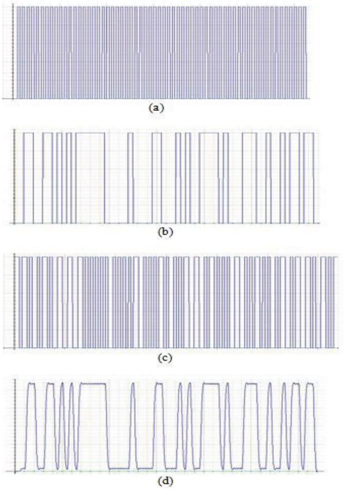
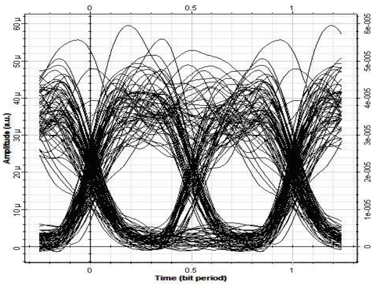


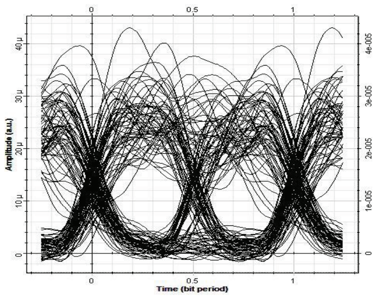
Fig. 4. BPPM simulation signals. (a) The clock signal. (b) The information signal. (c) The modulated BPPM signal. (d) The detected signal at receiver

The BER is monitored after the complete simulation system link is build. BER is defined as the probability of incorrect bit identification by the decision circuit [7]. High BER shows the poor FSO system links while low BER gives an accepted and good links. The performance of BER in this simulation system is investigated for various parameters such as gain of APD receiver and different scintillation index.

Figure 5 (a) and (b) shows the eye diagram for scintillation index 0.20 and 0.35. For scintillation index 0.20, the eye height of eye diagram is bigger than eye height for scintillation index 0.35 for the same APD gain. While for BER, the scintillation index of 0.20 shows smaller BER than scintillation index 0.55. As expected, the increasing atmospheric turbulence results in an increase in the required signal level to achieve the same performance.



Eye diagram for scintillation index 0.20
Eye height 1.4224X10^{-5}
Minimum BER 2.9295X10^{-7}
(a)



Eye diagram for scintillation index 0.35
Eye height 5.8143X10^{-6}
Minimum BER 3.0774X10^{-5}
(b)

Fig. 5. BER for APD gain 150 (a) The eye diagram for scintillation index 0.20. (b) The eye diagram for scintillation index 0.35

From equation (2), an APD gain also affects the BER for BPPM system. The suitable value of APD gain helps to get best BER for same scintillation index. To realize that, the simulation system model is done for three scintillation indexes, which are scintillation index 0.20, 0.35 and 0.55. Figure 6 shows the results of BER versus APD gain for various scintillation indexes. The graph shows the improvement of BER with increasing APD gain. But, at APD gain more than 170, the BER starts to increase. This is because the large APD gain leads to an increase in excess noise factor, and results the increase of BER.

The simulation system result for scintillation index 0.35 is compared with the analytical result. The APD gain is fixed. Figure 7 shows the BER comparison between simulation system and analytical result. From the graph, a conclusion can be made. The simulation system results follow the same trend of analytical results. They are slightly different in the value due to some neglecting and approximation values of parameters in simulation system.

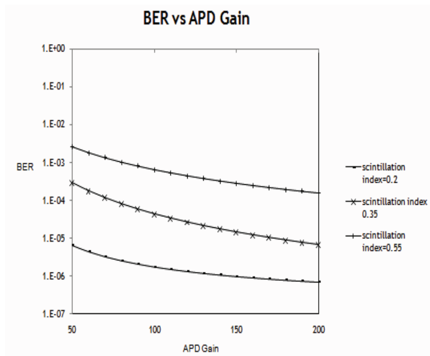


Fig. 6. BER vs APD gain for various scintillation index of turbulence

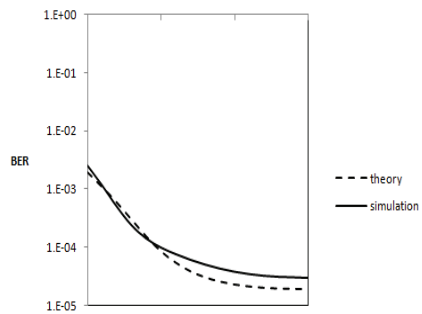


Fig. 7. the comparison between mathematical and simulation system results using scintillation index 0.35.

VI. CONCLUSION

This paper successfully studied the BER performance of BPPM with turbulent atmosphere in FSO. The simulation system results are done using Optic Software (OptiSys) and the BER is investigated for various parameters. The simulation system results are then compared to the analytical results. The contribution can be extended for various types of PPM in FSO.

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REFERENCES

[1] Willebrand and S. Ghuman, "Free-Space Optics: Enabling Optical Connectivity in Today's Networks," Sams Publishing, 2002

[2] H. Manor and S. Arnon, "Performance of an Optical Wireless Communication System as a Function of Wavelength," Applied Optics, vol. 42, no. 21, pp. 4285-4294, July 2003

[3] S. Arnon, "Optical Wireless Communications," Encyclopedia of Optical Engineering, pp. 1866-1886, 2003

[4] Kamran Kiasaleh, Tsun Yee Yan and Meera Srinivan, "Trellis Coded Pulse Position Modulation for Optical Communication Systems Impaired by Pulsewidth Inaccuracies," Journal of Lightwave Technology, vol. 17, pp. 1336-1346, no. 8, August 1999

[5] Jagtar Singh and V. K. Jain, "Performance Analysis of BPPM and M-ary PPM Optical Communication Systems in Atmospheric Turbulence," IETE Technical Review, vol. 25, issue 4, July-August 2008

[6] David G. Aviv, "Laser Space Communications," Artech House Inc. Computer Vision, 2006

[7] Arun K. Majumdar and Jennifer C. Ricklin," Optical and Fiber Communications Reports: Free-Space Laser Communications," Springer, 2008

[8] Robert M. Gagliardi and Sherman Karp, "Optical Communications," John Wiley and sons, Inc., second edition, 1995

[9] N. Tahir, N. M. Saad, B. B. Samir, V. K. Jain, and S. A. Aljunid, "Performance Comparisons of Theoritical and Simulation for Binary Pulse Position Modulation in Free Space Optical Communication Systems," Proc. World Academy of Science, Engineering and Technology, vol. 62, pp. 737-740, no. 132, February 2010 (Conference proceedings)

[10] Kamran Kiasaleh, "Performanced of APD Based, PPM Free Space Optical Communication Systems in Atmospheric Turbulence," IEEE Trans. on Communications, vol. 53, no. 9, September 2005

[11] Lucie Dordova and Otakar Wilfert, "Laser Beam Attenuation Determined by the Method of Available Optical Power in Turbulent Atmosphere," Journal of Telecommunications and Information Technology, vol.2, 2009

[12] E. Korevaar, I. Kim, and B. Mc Arthur, "Atmospheric Propagation Characterictics of Highest Importance to Commercial Free Space Optics," Proc. SPIE (Atmospheric Propagation), vol. 4976, pp. 1-12, 2003

[13] A. Naboulsi, M. Sizun, and F. De Fornel, "Propagation of Optical and Infrared Waves in the Atmosphere," Proc. XXVIIIth URSI Gener. Assem., pp. 1-4, New Delhi, India, 2005

[14] J. H. Franz and V. K. Jain, "Optical Communication; Components and Systems," Alpha Science International Ltd., 2000

[15] John Hamkins and Bruce Moision, "Selection of Modulation and Codes for Deep Space Optical Communications," Jet Propulsion Laboratory, California Institute of Technology